VERBAL LEARNING DURING TIC SUPPRESSION
IN CHILDREN WITH A CHRONIC
TIC DISORDER

by

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ABSTRACT

This study experimentally tested the effects of concurrent tic suppression on a verbal learning task in children with a chronic tic disorder in a semirandomized age-matched between groups design using reinforced suppression and tic freely groups. Analyses revealed equal initial learning and immediate recall of words between groups, but the suppression group was able to recall fewer words relative to the control group following a delay while concurrently suppressing. Following a release from suppression and long-delay period, the suppression group again freely recalled an equal number of words but recognized fewer words when presented with a list of words. Despite statistically equal performance between groups at some time points of the task, all means for the suppression group were less than that of the control group. Taken together, these results suggest that tic suppression interferes with registration of newly learned verbal information in long-term memory as well as retrieval of said information while suppressing. Further data collection may reveal that tic suppression results in more broad impairment across learning constructs (i.e., working memory, encoding, registration). This study has implications for people with tic disorders and behavioral treatments of tic disorders.

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INTRODUCTION

Definition of Tic Disorders

Tic disorders (including Tourette syndrome and Chronic Tic Disorder: TS/CTD) are childhood onset neuropsychiatric disorders characterized by sudden, rapid, recurrent, nonrhythmic, involuntary motor and vocal tics (American Psychiatric Association, 2013). Tics typically onset between 5 and 7 years of age, worsen across all dimensions of severity (i.e., number, frequency, intensity, complexity) from onset through late childhood, peak in severity between the ages of 10 and 12, and then decrease in severity (even without treatment) in adulthood (Bloch, Peterson, Scahill, Otka, Katsovich, Zhang et al., 2006). While the exact cause of CTD is unknown, there is strong evidence that tics result from dysfunction in the basal ganglia (BG) and associated cortical-striatal-thalamic-cortical (CSTC) neural circuitry. The current leading hypothesis of dysfunction focuses on action selection in the BG. In this model tics result from an excitatory abnormality in the striatum, leading to inhibition in the globus pallidus interna (GPi). The inhibitory impulse in the GPi is relayed through the thalamus to produce disinhibition in motor cortical neurons, which in turn leads to the execution of tics (for a full review see Albin & Mink, 2006).

Tic Suppression

One of the more interesting aspects of tics is that although they are involuntary, they can be temporarily suppressed with active inhibitory effort (Leckman, 2003). It is well known that most adults and children with tics report that they often attempt to suppress their tics, especially in certain environmental contexts such as social gatherings or school (Comings & Comings, 1985). Recent laboratory research has also demonstrated that even young children can suppress their tics for prolonged periods, especially when reinforced for doing so (Conelea & Woods, 2008; Himle & Woods, 2005; Woods & Himle, 2004). In addition, several empirically-supported behavioral interventions for tics capitalize on tic suppression as a central component of the treatment. For example, a treatment called habit reversal training teaches patients to employ tic-incompatible response behaviors to prevent the tic from occurring (Piacentini, Woods, Scahill, Wilhelm, Peterson, Chang et al., 2010). Another treatment known as exposure and response prevention exposes children to aversive tic-antecedent internal sensations and then practices suppression until the aversive sensation habituates (Verdellen, Keijsers, Catch, & Hoogduin, 2004; Wilhelm, Peterson, Piacentini, Woods, Deckersbach, Sukhodolsky et al., 2012). Both of these treatments have shown to produce lasting reductions in tic frequency, intensity, and overall severity. Some have argued that practice of tic suppression across the lifetime may be responsible, at least in part, for severity reductions seen in adulthood (Himle, Woods, Piacentini, & Walkup, 2006).

Though tic suppression is common and suppression related intervention strategies have shown benefit, there have also been historical concerns that it may have deleterious effects. Concerns regarding worsening of tics have not found empirical support (e.g., Himle & Woods, 2005; Meidinger et al., 2005; Piacentini et al., 2010; Wilhelm et al., 2012; Woods et al., 2008; Woods, Miltenberger, & Lumley 1996). However, concerns have been raised that tic suppression may recruit cognitive resources away from other pertinent activities (e.g., Conelea & Woods, 2008) thereby interfering with learning of suppression-concurrent tasks (e.g., academic tasks), though this concern has received little empirical investigation.

Executive Function and Tic Suppression

The specific cognitive processes involved in tic suppression remain unclear, though there is some evidence that tic suppression relies on executive functions (EF; Peterson, Skudlarski, Anderson, Zhang, Gatenby, Lacadie et al., 1998), which is an "umbrella" term encompassing several cognitive abilities including (but not limited to) decision making and engaging in goal-directed behavior, working memory, inhibition, and response selection (e.g., Suchy, 2009). EF skills also subserve the ability to inhibit and override prepotent responses, acquire and store newly learned information, and make decisions based upon previously learned information. The prefrontal cortex (PFC) is often cited as the seat of EF, though these resources also rely on intact complex neural networks that include the basal ganglia, thalamus, cerebellum, and non-prefrontal areas of the cortex.

In the only known imaging study of tic suppression, Peterson and colleagues (1998) examined brain activity during volitional tic suppression using functional magnetic resonance imaging and found some evidence for the role of EF in tic suppression. The study found that, when compared with resting periods, cortical activation signals increased and subcortical (i.e., basal ganglia) activation signals decreased, indicating a “top down” process of control. These results suggest that tic suppression is dependent upon activating prefrontal cortical networks (i.e., executive resources) to down-regulate otherwise abnormally high activity in CSTC circuits that are typically implicated as dysfunctional in CTD. Furthermore, the neural networks implicated for tic suppression in this study overlap with those required in attention demanding tasks, suggesting that sustained attention is necessary for tic suppression. Additionally, this same study also found decreased activation signals in memory-related structures including hippocampal, parahippocampal, and posterior cingulate cortices during tic suppression.

In a behavioral study, Conelea and Woods (2008) also found some evidence for the role of EF in tic suppression. They examined the effects of an attention-demanding distraction task on tic suppression in a sample of 9 children and adolescents with CTD. They used a within-subjects alternating treatment design whereby each participant was instructed to tic freely, suppress their tics only (using differential reinforcement; DRO), or suppress their tics (using DRO) while simultaneously engaging in an auditory distraction task. They found that distraction did not appear to impact the child’s ability to suppress his or her tics, however, performance on the distraction task *was* impaired during the suppression task (compared with the mean nonsuppression baseline score), providing preliminary evidence that tic suppression might negatively impact performance on EF-demanding tasks.

Based on these two studies, additional research examining the effects of tic suppression on concurrent EF-demanding tasks seems warranted. The results from

Peterson et al. (1998), for example, suggest that tic suppression requires activation of the PFC to down-regulate subcortical activity. Given that these areas in the PFC overlap with those required for EF, if executive resources are being recruited to suppress tics, these resources might be less available for acquiring and storing new information. Decreased activation in memory systems during tic suppression (Peterson et al., 1998) may then further decrease the ability to encode and/or retrieve information learned during tic suppression. This is of particular concern in an academic context for children and adolescents who are known to attempt to suppress their tics in academic settings (e.g., Comings & Comings, 1985). In an academic setting, the effects of tic suppression on attention and thus working memory are pertinent. Working memory can be broadly defined as the ability to temporarily store or "hold" information in short-term memory and to manipulate this information if necessary (Baddeley, 2003). Additionally, working memory is necessary to then encode information into long-term memory storage in order to facilitate efficient future retrieval of information (Wood, Baxter, & Belpaeme, 2012).

Current Study

The overarching aim of the current study is to examine the effects of tic suppression on the learning of new verbal information. Specifically, the study examined whether tic suppression interferes with registration, encoding, and retrieval of information presented during a concurrent tic suppression task. To do so, we compared performance on a verbal learning task (the California Verbal Learning Task – Child Version, CVLT-C; Delis, Kramer, Kaplan, & Ober, 1994) administered to subjects who were randomly assigned to a concurrent tic suppression condition versus a nonsuppression (i.e., free-to-tic) condition using a between groups design. Our hypothesis was that tic suppression would interfere with immediate learning of new verbal information such that those assigned to a reinforced suppression condition (see Method section for detailed explanation) would correctly recall and/or recognize fewer words relative to a tic-freely control condition. Detailed analyses of CVLT-C recall and recognition tasks would indicate where in the learning process (registration, retrieval, and/or encoding) interference, if any, occurs.

METHOD

Participants

Participants were 31 children, ages 8 to 17 years, with a diagnosis of a chronic tic disorder. Twenty-seven children met DSM-IV-TR (American Psychiatric Association, 2000) criteria for Tourette's disorder and 4 met criteria for chronic motor tic disorder. Given the high rates of comorbidity in CTD samples, comorbid psychopathology was allowed as long as it did not, in the opinion of the investigators, interfere with study participation or compliance with study procedures. Participants with a history of an intellectual or developmental disorder/delay were excluded. Clinical and demographic characteristics for the sample are detailed in Table 1.

Measures

Diagnostic and Clinical Measures

The Yale Global Tic Severity Scale (YGTSS; Leckman, Riddle, Hardin, Ort, Swartz, Stevenson et al., 1989) was used to assess tic severity. The YGTSS provides separate severity ratings for motor tics and vocal tics each ranging from 0-25, which can then be summed for a global severity score ranging from 0-50 (when both motor and vocal tics are present). The Anxiety Disorders Interview Schedule, Child Version (ADIS-C; Silverman & Albano, 1996) was used to assess for the presence of common comorbid psychopathology.

Experimental Measures and Variables

California Verbal Learning Test—Children's Version (CVLT-C). The CVLT-C (Delis et al., 1994) is a verbal learning task that requires the child to remember and retrieve a list of 15 words that can be categorized semantically, but are not presented to the child in a categorized fashion. The child is read the list (list A) during five consecutive trials and is asked to recall, in any order, as many words as possible in each trial. After the fifth trial, the child is then read a distractor list (list B) of 15 words and asked to recall as many words as possible from list B (i.e., retroactive interference). Following this single learning trial for list B, the child is then asked to recall list A ("short delay" free recall) in order to assess short-term encoding and retrieval. After a 20-min delay, participants are then asked to recall (freely) as many words as possible from list A. Immediately following this "long-delay" free recall, participants are then asked to recall as many items as possible when cued with three semantic category labels (cued recall). Finally, following the cued recall, participants are then read a series of items and asked (yes/no) if the item was listed in list A (recognition). We report only on free recall and recognition trials in this study.

Video Coding

All tapes were coded for tic frequency by trained research assistants. Video coding utilized frequency coding to determine rate of tics throughout all phases of the second study visit. Coding data were used as a manipulation check to ensure suppression occurred. Interobserver agreement for each participant ranged from 78% to 92%.

Procedures

This study was part of a larger multisite project examining the impact of tic suppression on EF. Each participant attended two study visits at either the University of Utah or the University of California, Los Angeles (UCLA). Study visits were overtly video-recorded in full. All study procedures were approved by the University of Utah and UCLA Institutional Review Boards. For a visual schematic of study procedures, please see Figure 1.

Visit 1

The first visit consisted of a clinical assessment and eligibility screen. During this visit, the YGTSS and ADIS-C were administered by a trained clinical psychology doctoral student. Two subtests (vocabulary and matrix reasoning) from the Wechsler Intelligence Scale for Children, 4^{th} edition (WISC-IV; Wechsler, 2003) were administered to obtain an estimate of IQ.

Visit 2

Having confirmed eligibility during visit 1, participants returned for visit 2. Investigators reviewed the YGTSS list of tics with the parent and child prior to beginning testing in order to determine if any new tics had presented since visit 1. Following the review of tics, participants were randomized to either a suppression challenge or control condition. Because of the wide range of ages allowed in this study, we matched participants on age across conditions where possible. For example, if the first 12-year-old was randomized to the experimental condition, the next 12-year-old who enrolled in the study was assigned to the control condition.

DRO Suppression Computer Program

The DRO procedure was delivered via a digital adaptation of the DRO tic suppression paradigm developed by Himle and Woods (see Himle & Woods, 2005; Woods & Himle, 2004). A trained observer was behind a one-way mirror monitoring the participant for tic occurrence. Participants were presented with a 10-s countdown timer on a computer monitor. The timer continuously counted down from 10 to zero. If the participant did not tic before the timer reached zero, she or he received a point signaled by a green “+1” appearing on the screen for 1-s (i.e., positive reinforcement of a zero-rate behavior). The countdown timer then reset to 10 and began the countdown of the next interval. If the observer witnessed the participant tic, he/she pressed the space bar on a keyboard and a blue circle appeared on the screen indicating to the participant that she or he ticced. The timer reset to 10-s and the participant did not receive a point for that interval. Participants were informed that points could be exchanged for a gift card to a local retailer (Note: due to IRB regulations, all participants in both conditions receive a gift card of equal value at the end of the visit regardless of performance). Prior to initiating the suppression challenge, the investigator explained the program to the participant, and displayed an example on the screen. The investigator did not provide the participant with any strategies for suppression.

Control Computer Program

In order to maintain similar testing conditions across groups, a 10-s countdown timer identical to the suppression condition continuously counted down from 10 to zero on a computer monitor for the control group. An observer was overtly seated behind a one-way mirror. Participants assigned to the control condition did not receive differential reinforcement (i.e., green +1 visual stimulus), nor were they presented with the blue circle contingent upon tic occurrence.

Suppression Challenge

For the first 5-min participants only attempted to suppress their tics and were not engaged in any other activity. Following this 5-min period, the examiner administered the CVLT-C (Delis et al., 1994) learning trials 1-5, distraction list, and short-delay free and cued recall tasks while the participant concurrently attempted to suppress her/his tics. Following these tests participants were asked to continue suppressing their tics for a 10-min period to allow for appropriate time for delayed recall trials. During this time participants were not engaged in any other tasks. At the end of this 10-min period participants were told that they no longer needed to suppress their tics, and were allowed a 5-min break if desired.

Postsuppression Testing

Following the suppression challenge (and equivalent testing period for control participants), participants received the long-delay tasks from the CVLT-C (free recall, cued recall, and recognition trials; Delis et al., 1994) after the designated delay period.

Control Condition

Participants in the control condition were instructed to tic freely as normal throughout the duration of the study. For the first 5-min control participants were not engaged in any task and sat in a chair waiting for testing to begin. At the end of this 5-min period the examiner administered the CVLT-C (Delis et al., 1994) learning trials 1-5, distraction list, and short-delay free and cued recall tasks. Following administration of these tasks, participants were asked to wait 10-min while not engaged in any tasks. Participants were then allowed a 5-min break if desired. Following this period, the examiner then delivered the long-delay tasks from the CVLT-C (free recall, cued recall, and recognitions trials; Delis et al., 1994) after the designated delay period.

Definition of Constructs

Recall of words in CVLT-C learning trials 1-5 was used as an index of immediate learning (i.e., without delayed recall). Registration was defined as the acquisition and retention of information (i.e., new information is attended to and registered in memory). Registration was evidenced by the ability to correctly recognize previously learned information at the end of the test. Retrieval was defined as the ability to access information during free recall trials. Encoding was defined as the "efficient storage" of information thus facilitating retrieval. The reader will note that these definitions are for ease of reference, and do not necessarily reflect a particular theory of learning or memory.

Analytic Plan

All analyses were conducted using SPSS/PASW v18.0 statistical software. Prior to conducting tests of the hypotheses, we compared groups on relevant demographic variables including age, IQ estimate, and tic severity using independent samples t-tests with experimental condition used as a binary grouping independent variable. We also compared tic rates obtained from video coding between the two groups to ensure that suppression did indeed occur. We used CVLT-C raw scores for all analyses and included age and IQ estimate as covariates.

Table 1. Participant Characteristics by Experimental Group

Group	Control	Suppression	Post-Suppression
Gender (N, % group)			
Male	10 (58.8%)	9 (64.2%)	6 (75.0%)
Female	7 (41.2%)	5 (35.8%)	2 (25.0%)
Total	17 (100%)	14 (100%)	8 (100%)
Age	11.41 (2.79)	11.07 (2.76)	11.75 (3.15)
Tic Disorder Diagnosis (N, % group)			
Tourette Disorder	11 (78.6%)	13 (92.9%)	8 (100%)
Chronic Motor Tic Disorder	3 (21.4%)	1 (7.1%)	0 (0%)
YGTSS (M, SD)			
Total Tic Severity	25.06 (9.20)	25.93 (6.15)	27.67 (5.55)
Total Motor Tic Severity	15.53 (3.91)	14.80 (2.70)	15.78 (2.38)
Total Vocal Tic Severity	9.53 (6.54)	11.13 (4.44)	11.89 (3.92)
IQ Estimate (M, SD)	107.00 (11.97)	111.15 (11.61)	111.71 (11.37)
Comorbid Diagnoses (N, % group)			
ADHD inattentive	0 (0%)	2 (14.3%)	0 (0%)
ADHD hyperactive/impulsive	0 (0%)	1 (7.1%)	1 (12.5%)
ADHD combined	3 (17.6%)	2 (14.3%)	2 (25.0%)
OCD	3 (17.6%)	2 (14.3%)	1 (12.5%)
Social anxiety disorder	5 (29.4%)	2 (14.3%)	2 (25%)
Generalized anxiety disorder	5 (29.4%)	5 (35.7%)	3 (37.5%)
Specific phobia	4 (23.5%)	4 (28.6%)	2 (25.0%)
Oppositional defiant disorder	1 (5.9%)	2 (14.3%%)	1 (12.5%)

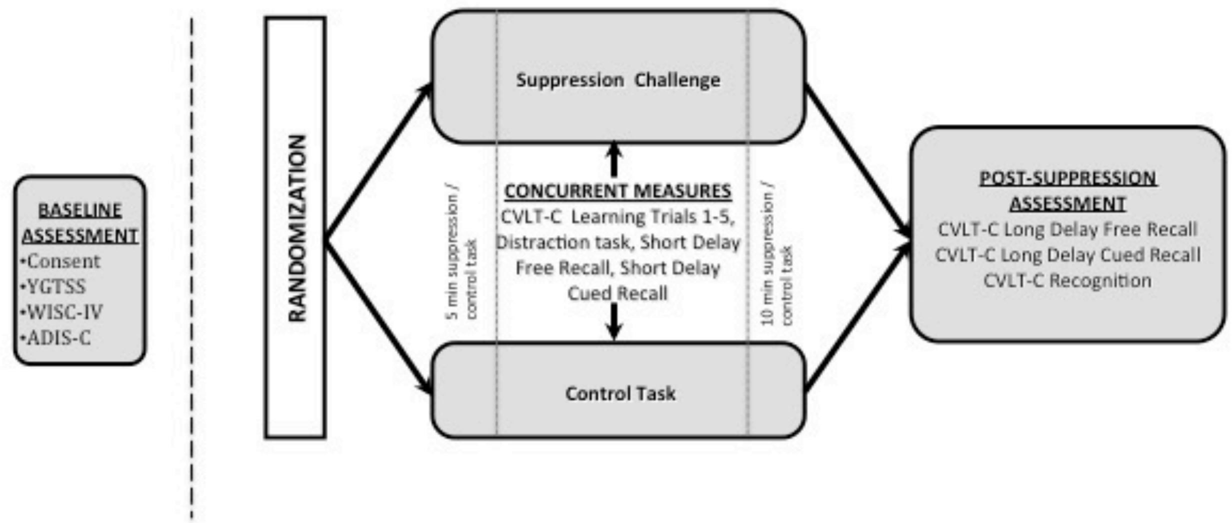

Figure 1. Study flow chart illustrating the timing and order of study procedures

RESULTS

Results of Baseline Characteristics and Experimental Manipulation

The experimental groups were compared on relevant baseline variables. The groups did not differ on age ($t(29) = .340$, $p = .736$), YGTSS global tic severity ($t(29)$, = .425, $p = .674$), or IQ estimate ($t(28) = .954$, $p = .348$). Please see Table 1 for additional baseline characteristics by group.

Tic rate for each experimental phase was calculated by summing the number of tics in a given phase and dividing by the number of minutes in that phase (which varied by individual participant). Due to study design, the timing of each experimental phase varied based on individual completion time of study tasks. Tic rates for the control group were stable across all experimental phases (all ps>.05). Paired samples t-test showed that the average tic rate for the suppression group decreased significantly from baseline to suppression (71.3% reduction, $t(11) = 3.27$, $p = .007$), confirming that the suppression group, but not the control group, showed evidence of tic suppression. Six participants were excluded from postsuppression analyses due to an experimenter administration error. Tic rates then significantly increased following a release from suppression ($t(6) = 2.674$, $p = .037$) to near baseline rates. Postsuppression tic rates were slightly, though significantly, lower than baseline levels (25.2% less than baseline, $t(6) = 4.961$, $p = .003$) consistent with previous studies of reinforced tic suppression (e.g., Himle & Woods, 2005).

Results of Main Analyses

A univariate ANCOVA was used to examine group differences on immediate learning trials administered during suppression. Age and IQ estimate were entered as covariates in all analyses below. Results showed that the experimental groups did not differ significantly from each other in number of words recalled at immediate learning trial 1, immediate learning trial 5, or the total number of words recalled across the immediate learning trials (all ps > .05).

A series of univariate ANCOVAs was used to compare group differences on delayed recall (i.e., short-delay free recall and long-delay free recall) and recognition tasks. In each analysis, each recall/recognition task was entered as a dependent variable (DV) and experimental condition as a between subjects factor. Age and IQ estimate were entered as covariates in the model. Because of an experimenter administration error 6 participants from the suppression condition were excluded from the postsuppression (i.e., long-delay free recall and recognition task) analyses. Controlling for age and IQ estimate, there was a significant main effect of condition at short-delay free recall with the suppression group correctly recalling fewer words ($F(1, 26) = 4.601$, $p = .041$, *Cohen's d* = 0.58, *observed power* .542, $M_{\text{control}} = 10.82$, $SD_{\text{control}} = 2.40$, $M_{\text{suppression}} = 9.13$, $SD_{\text{suppression}} = 3.31$), as well as on the recognition task, again with the suppression group performing more poorly ($F(1, 21) = 6.124$, $p = .022$, *Cohen's d* = 0.78, *observed power* .665, $M_{\text{control}} = 14.35$, $SD_{\text{control}} = .99$, $M_{\text{suppression}} = 13.11$, $SD_{\text{suppression}} = 2.03$). There was not a significant group difference on the long-delay free recall task ($F(1, 21) = 1.694$, $p = .207$, $M_{\text{control}} = 11.35$, $SD_{\text{control}} = 1.66$, $M_{\text{suppression}} = 10.22$, $SD_{\text{suppression}} = 4.06$, *Cohen's d* = 0.36). Results are presented in Table 2 and are visually represented in Figure 2.

Table 2. Mean Scores By Group on CVLT-C Variables.

	M (*SD*)	
Task	Suppression	Control
Trial 1	6.00 (2.20)	6.94 (1.78)
Trial 5	10.93 (3.61)	11.63 (1.86)
Total Recall Trial 1-5	43.87 (12.16)	50.75 (9.75)
Short Delay Free Recall*	9.13 (3.31)	10.82 (2.40)
Long Delay Free Recall†	10.22 (4.06)	11.35 (1.66)
Recognition Correct Hits*†	13.11 (2.03)	14.35 (.99)

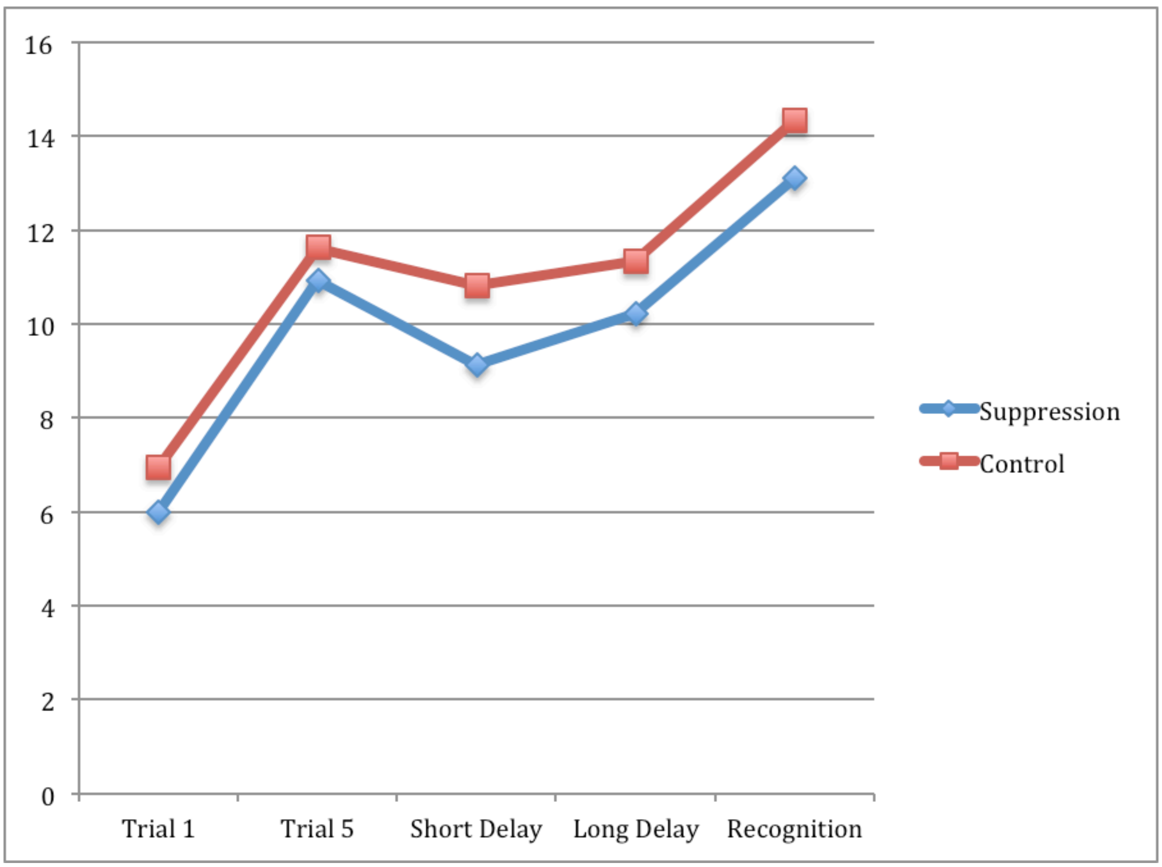

Figure 2. Plot of marginal means of CVLT-C raw number of words recalled at short- and long-delay free recall tasks and recognition task.

DISCUSSION

Children and adults with CTDs report that they frequently attempt to suppress their tics and tic suppression is a primary component of several efficacious tic management interventions (Leckman, 2003). It has been argued that although repeated attempts at tic suppression may have short- and long-term benefits, it may also have costs, such as interfering with concurrent learning (Conelea & Woods, 2008; Peterson et al., 1998). The primary aim of the current study was to determine where active tic suppression interferes with learning of new verbal information. Analyses revealed no group differences in the immediate learning trials on the CVLT-C, suggesting that tic suppression does not have deleterious effects on immediate recall of information (i.e., working memory). However, a significant between-group difference was found at short-delay after controlling for age and IQ with the suppression group performing more poorly on the short-delay free recall task. The mean number of words recalled for both groups increased from short-delay to long-delay free recall. Though mean number of words recalled at the long-delay free recall task was also lower for the suppression group relative to the control group, this difference was not statistically significant. This pattern of findings might suggest that tic suppression interferes with the retrieval but not encoding of newly learned information. However, similar free recall performance between the two groups at long delay suggests that encoding to facilitate long-term recall remained intact. Analyses also revealed that the suppression group correctly recognized fewer words than did the control group, suggesting that less information was registered in long-term memory.

The current results suggest that tic suppression may interfere with specific aspects of verbal learning. In particular, both retrieval and registration, but not encoding of information, were impaired in the suppression group relative to the control group. The number of words freely recalled while actively suppressing is impaired relative to a tic freely control condition. When attempting to freely recall information following a time delay and release from suppression (i.e., long-delay free recall), those in the suppression group recalled the same number of words as those in the control group. This difference at short delay but equal performance at long-delay suggests that encoding (i.e., the ability to efficiently store information in long-term memory to facilitate later retrieval) remained intact relative to the control group. Because of equal performance at long delay, when the suppression group had stopped suppressing, the difference at short delay is attributed to concurrent tic suppression, thus implicating retrieval interference. The suppression group (during the postsuppression tic freely period) recognized slightly, though significantly, fewer words than the control group, indicating that suppressing tics while learning new information may impair registration of information in long-term memory (i.e., information is not registered in long-term memory and is thus later unrecognizable). However, even though children who suppressed their tics correctly recognized fewer words than those in the control group, they still recognized far more words than they were able to freely recall. Because groups performed equally at long delay and recognized more words than they freely recalled, it does not appear that registration interference impacts free recall.

These results are consistent with previous studies which suggested that tic suppression may interfere with attention-demanding tasks (Conelea & Woods, 2008); potentially because tic suppression appears to rely on neural networks that have overlap with learning and memory. Thus, concurrent suppression may interfere with these functions that are required for attention demanding tasks (Peterson et al., 1998). This study begins to clarify which processes may be affected (i.e., retrieval and recognition), though given the small sample size, these findings should be considered preliminary. It may be that in a larger sample a group difference does emerge on the long-delay free recall task. If such a finding emerged and other findings remain constant, this would reflect encoding interference instead of retrieval interference.

These data suggest that suppression-related verbal learning interference is not broad. In the processes where suppression does appear to interfere (i.e., registration and retrieval), this interference does not appear to be profound. Indeed, on the short-delay recall and recognition tasks, the group means differed by less than two words. In addition, it is likely that there are individual differences in the degree to which suppression interferes with learning across children, and it is also possible that how suppression interferes with learning (e.g., encoding vs. retrieval) varies across children depending upon the child's cognitive skills and the suppression strategy they employ. Understanding individual differences related to "costs" of suppression will be important in the future for providing clinical recommendations regarding tic suppression.

Notably, the results of the present study only examine a narrow scope of potential costs of suppression and do not examine potential benefits that may result from suppression. Thus, while it appears tic suppression may cause mild interference in verbal learning, it is entirely possible that suppression has other, potentially long-term, benefits. As we learn more, it will be important to understand in more detail in which situations tic suppression may be "costly" such that children can be instructed to avoid tic suppression in certain times, instead of broad advice to never suppress tics if suppression does indeed have benefits.

This study has a number of limitations. First, the small sample size limited the power to detect group differences. This limitation was exacerbated by a procedural administration error causing us to exclude 6 participants in the suppression condition from the long delay and recognition task analyses. Second, though observed effects are attributed to suppression generally, the current study does not specify why suppression may interfere with learning. Effects may indeed be due to overlapping neural networks (Peterson et al., 1998), but may also be due to attempting to maintain concurrent mental sets and thus result in task switching (i.e., switching between attending to tic suppression and to the learning task). Additionally, because suppression is an effortful process, differences may also be attributable to fatigue and/or lack of motivation, and thus suppression participants might avoid further cognitive effort inherent in a learning and memory task after engaging in effortful suppression for an extended period of time. This effect may be more pronounced for some children than others. A repeated measures study design, controlling for practice effects and measuring baselines characteristics would likely aid in understanding of factors affecting tic suppression and potentially resulting in learning and cognitive interference. Finally, while the current study uses a widely-used and well-validated learning task, the effect sizes on observed differences were moderate and the extent to which these findings generalize to external settings and environments (e.g., school) for children with CTDs is unclear. Continued investigation in this area may yield recommendations for when suppression may or may not be deleterious to learning. Though suppression strategies, such as a competing response, were not given in this study, future research may begin to clarify and provide more specific recommendations on when and when not to use suppression-related treatment strategies, or even when to avoid general suppression. Studies may also seek to understand longer periods of suppression more akin to ecologically valid representations of “real world” suppression, such as a school day, which takes place over several hours that may have several periods of sustained suppression throughout the day.

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